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ScienceDirect
Vision Research 46 (2006) 3586–3593
Vision Research
www.elsevier.com/locate/visres

Distance impairs postural stability only under binocular viewing

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Received 20 December 2005; received in revised form 23 June 2006

Abstract

Prior studies indicate that postural stability under binocular viewing is not better than under monocular viewing. This was tested at the distances of 145 cm [Fox, C.R. (1990). Some visual influences on human postural equilibrium: binocular versus monocular fixation. *Perception and Psychophysics, 47* (5), 409–422] and 90 cm [Isotalo, E., Kapoula, Z., Feret, P.H., Gauchon, K., Zamfirescu, F., & Gagey, P.M. (2004). Monocular versus binocular vision in postural control. *Auris Nasus Larynx, 31* (1), 11–17]. On the other hand, postural stability is known to decrease with distance increase. We re-examined the effect of binocular versus monocular viewing on postural stability at near and far distances (40 and 200 cm), and for both young (25.7 ± 2.7 years), and old subjects (61.2 ± 4.6 years). For both groups of subjects, proximity decreased the area of CoP, the standard deviation of antero-posterior sway (SDy) and the variance of speed. The group of elderly presented increased variance of speed at far distance in comparison with young subjects. The novel finding is the interaction between distance and viewing condition. Under binocular viewing, the area of CoP was significantly higher at far distance than at near; in contrast, monocular viewing produced similar CoP values at both distances. Increased instability at far distance when both eyes are viewing is attributed to decreased sensitivity to binocular disparity cues and to visual motion in depth resulting from body sway. Monocular viewing would provide similar stability at far and at near distance, because sensitivity to lateral visual motion, detected monocularly, decreases less with distance than sensitivity to binocularly detected motion in depth. Alternatively, such monocular viewing could increase subject's attention and lead to tighter postural control regardless of the distance.

Keywords: Postural stability; Binocular and monocular viewing; Distance; Ageing

1. Introduction

Vision plays a major role in postural control. Indeed, closure of the eyes impairs balance i.e. the Romberg test (Gagey & Weber, 1999). Vision has a spatial component, including horizontal, vertical direction and depth. Several studies showed that postural stabilization improves when distance between subject's eye and target decreases (Bles, Kapteyn, Brandt, & Arnold, 1980; Brandt, Paulus, & Straube, 1986; Paulus, Straube, Krafczyk, & Brandt, 1989; Paulus, Straube, & Brandt, 1984). The diminishment of distance increases the angular size of retinal slip induced by body sway and renders it easier to detect. In a previous study (Kapoula & Le, 2006), we found that while viewing at far the use of prisms that force the eyes to converge improves postural stability, even though the angular size of retinal slip remains the same. This result led us to conclude that in addition to retinal slip, efferent and afferent signals from extra-ocular muscles related to convergence of the eyes are involved in postural stabilization.

Body sway in side-by-side feet position is believed to be controlled by two distinct muscular strategies (ankle for antero-posterior "AP" sway, and hip for medial–lateral "ML" sway; see Day, Steiger, Thompson, & Marsden, 1993; Gatev, Thomas, Kepple, & Hallett, 1999; Winter, Patla, Ishac, & Gage, 2003; Winter, Prince, Frank, Powell, & Zabjek, 1996). Fox (1990) found that AP sway is less under binocular than that under monocular vision when the dominant eye is viewing; this is the case in both standard and sharpened (heel-to-toe position) Romberg stance.

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0042-6989/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.visres.2006.06.018

Isotalo et al. (2004) showed better postural stability under binocular viewing but this was observed only in half of the subjects. The eye-target distance in the study of Fox (1990) was 145 cm, while in the study of Isotalo et al. (2004) this distance was 90 cm. As we mentioned above, the distance influences the postural stability. Furthermore, Fox (1990) analysed the root-mean square (RMS) of antero-posterior and lateral body sway while Isotalo et al. (2004) used the mean area of center of pressure (CoP) and did not provide detailed information about AP or ML sway. Fox (1990) used six experimental conditions (full illumination or dark room containing one, three or six LEDs) while Isotalo et al. (2004) used only one experimental condition that was a full illuminated room and required subjects to fixate a single cross. More careful examination of the data reported by Fox (1990), indicates that in the full illuminated room condition there is no statistically significant difference between binocular and monocular viewing (Wilcoxon test; $z = 1.31$; double side $p = .1902$, extracted from Table 1, page 414). Thus, the two studies (Fox, 1990; Isotalo et al., 2004) seem to converge on the point that there is no strong benefit of binocular viewing neither at the distance of 90 cm nor at the distance of 145 cm.

Indeed, powerful visual cues for postural stabilization can be monocular. Motion parallax (relative motion of far versus near objects) is such a cue, giving also depth information. Motion parallax was found to improve postural stabilization in both monocular and binocular viewing (Guerraz, Sakellari, Burchill, & Bronstein, 2000). This result is consistent with another study that found a direction change of postural sway in monocular viewing when depth perception was made available e.g. tunnel versus wall background (Masson, Mestre, & Pailhous, 1995). Finally, monocular stimulation of the temporal retinal region (the monocular crescent) increases postural response, the lateral sway was found to be stronger after right crescent stimulations while the antero-posterior sway was larger after left ones (Bessou, Severac Cauquil, Dupui, Montoya, & Bessou, 1999).

The notion of ocular dominance is widely used although the physiological meaning i.e. only sensory (Berardi, Pizzorusso, Ratto, & Maffei, 2003; Fischer et al., 2004; Nakagama & Tanaka, 2004; Taha & Stryker, 2002), only motor (Jones, Classe, Hester, & Harris, 1996; Mapp, Ono, & Barbeito, 2003; Portal & Romano, 1998), both sensory and motor (Handa et al., 2004), or the one sensory dominant and the other motor dominant (el-Mallakh, Wyatt, & Looney, 1993) is controversial. To determine the dominant eye, one usually asks the subject to align the finger with a target initially with the two eyes open, and then to judge the misalignment when either eye is closed alternatively (Heinrich, Kromeier, Bach, & Kommerell, 2005; Kommerell, Schmitt, Kromeier, & Bach, 2003). More recent studies (Heinrich et al., 2005; Kommerell et al., 2003) introduced another concept “the prevalent eye”. Subject fixates binocularly a target inside Panum’s area (area inside which the retinal fusion is possible); the eye that is better aligned to the target is the prevalent eye. Until now, in the field of postural stabilization only the influence of the dominant eye has been studied. Indeed, Gentaz (1988) proposed the existence of a “postural” eye which is not necessarily the dominant eye and which allows better stabilization during the quiet stance than the other eye or even when both eyes viewing.

The main purpose of this study is to re-examine the effect of binocular versus monocular vision for right eye ocular dominant subjects and in relation to the viewing distance; for this we use two rather extreme distances 40 cm and 200 cm.

Ageing effects on postural stabilization are widely studied (Corriveau, Hebert, Prince, & Raiche, 2001; Corriveau, Hebert, Raiche, Dubois, & Prince, 2004; Corriveau, Hebert, Raiche, & Prince, 2004). Many studies found an increment of the mean area of CoP in septuagenarians (Aufauvre, Kemoun, Carette, & Bergeal, 2005; Doyle, Dugan, Humphries, & Newton, 2004). In a previous study (Kapoula & Le, 2006), we did not find a similar increment of the area of CoP for the sexagenarians but an increase of the speed variance of the feet CoP. The variance of speed indicates the dispersion about the mean speed of the pressure. High speed variance suggests increased variance of feet pressure which is related to leg activity: the link between the shift of CoP and group muscles activity (for instance, the soleus, the gastrocnemus, the anterior tibialis) has been shown by Wang, Zatsiorsky, and Latash (2006). Thus, we argue that a first sign of senescence could be an increase of activity of the lower limb to stabilize the body. Our results were consistent with those of Amiridis, Hatzitaki, and Arabatzi (2003), Jonsson, Seiger, and Hirschfeld (2005) who found respectively an increase of the hip muscles activity, and an increase of activity of anterior tibialis muscle during the Romberg stance in elderly. In our previous study (Kapoula & Le, 2006), a similar effect of distance was found for both young and elderly i.e. better stability at near. In this study, we examined whether elderly have more difficulty to maintain postural stability than young when visual cues are reduced such as monocular viewing. Indeed, several studies showed decrease of binocular visual acuity (Ivers, Mitchell, & Cumming, 2000; Laitinen et al., 2005) or of stereoacuity (Zaroff, Knutelska, & Frumkes, 2003) with age. Yet, no studies exist comparing postural performances of young and elderly under monocular and binocular viewing.

2. Materials and methods

2.1. Subjects

Eighteen young and twenty older subjects working or living close to the laboratory participated in our preliminary tests; all the young and 17 of older subjects were considered as normal. One of the excluded subjects had Meniere’s disease, another had a mild difference of the length legs, and the other had unilateral amblyopia. Medical examination and several preliminary tests confirmed normal findings without neurological signs, and no medication.

Table 1
Corrected visual acuity at 5m and at 33cm for left eye (LE), right eye (RE) and both eyes, stereoacuity, near point of convergence (NPC), phoria ("X" corresponds to exophoria, "S" to esophoria, and "O" to absence of phoria) and the dominant eye for each subject

Subject (age)	Corrected visual acuity (5m)	Corrected visual acuity (33cm)	Stereoacuity (″)	NPC (cm)	Phoria	Dominant eye
Young subjects						
S1	LE : 14/10 Both: 14/10	LE : 9/10 Both: 9/10	40	4	Far: X	Right
(22)	RE : 14/10	RE : 9/10			Close: X	
S2	LE : 14/10 Both: 14/10	LE : 9/10 Both: 9/10	60	7	Far: X	Right
(25)	RE : 14/10	RE : 9/10			Close: X	
S3	LE : 8/10 Both: 12/10	LE : 9/10 Both: 6.6/10	40	9	Far: X	Right
(24)	RE : 8/10	RE : 9/10			Close: X	
S4	LE : 9/10 Both: 12/10	LE : 9/10 Both: 9/10	40	5	Far:	Right
(27)	RE : 10/10	RE : 9/10			Close:	
S5	LE : 10/10 Both: 12/10	LE : 9/10 Both: 9/10	40	3	Far: X	Right
(27)	RE : 10/10	RE : 9/10			Close: X	
S6	LE : 10/10 Both: 14/10	LE : 9/10 Both: 9/10	40	9	Far: X	Right
(23)	RE : 10/10	RE : 9/10			Close: X	
S7	LE : 9/10 Both: 9/10	LE : 6.6/10 Both: 9/10	80	5	Far: X	Right
(28)	RE : 8/10	RE : 6.6/10			Close: X	
S8	LE : Both:	LE : Both:			Far:	Right
(26)	RE :	RE :			Close:	
S9	LE : 9/10 Both: 12/10	LE : 9/10 Both: 9/10	40	5	Far: X	Right
(24)	RE : 9/10	RE : 9/10			Close: O	
S10	LE : 9/10 Both: 9/10	LE : 9/10 Both: 6.6/10	60	8	Far: S	Right
(22)	RE : 8/10	RE : 9/10			Close: S	
S11	LE : Both:	LE : Both:			Far:	Right
(33)	RE :	RE :			Close:	
S12	LE : 10/10 Both: 12/10	LE : 6.6/10 Both: 9/10	50	9	Far: X	Right
(25)	RE : 12/10	RE : 9/10			Close: X	
S13	LE : 8/10 Both: 10/10	LE : 9/10 Both: 9/10	50	8	Far: X	Right
(26)	RE : 10/10	RE : 9/10			Close: X	
S14	LE : 9/10 Both: 10/10	LE : 9/10 Both: 9/10	40	8	Far: X	Right
(27)	RE : 9/10	RE : 9/10			Close: X	
S15	LE : 10/10 Both: 10/10	LE : 6.6/10 Both: 9/10	40	8	Far: X	Right
(25)	RE : 9/10	RE : 9/10			Close: X	
S16	LE : 9/10 Both: 10/10	LE : 9/10 Both: 9/10	40	5	Far: X	Right
(27)	RE : 9/10	RE : 6.6/10			Close: X	
Elderly subjects						
S1	LE : 9/10 Both: 12/10	LE : 6.6/10 Both: 9/10	50	**13**	Far: X	Right
(66)	RE : 9/10	RE : 9/10			Close: X	
S2	LE : Both:	LE : Both:			Far:	Right
(58)	RE :	RE :			Close:	
S3	LE : 10/10 Both: 10/10	LE : **4/10** Both: 6.6/10	50	7	Far: O	Right
(71)	RE : 6/10	RE : **4/10**			Close: X	
S4	LE : 12/10 Both: 14/10	LE : 9/10 Both: 9/10	50	6	Far: X	Right
(58)	RE : 12/10	RE : 6.6/10			Close: X	
S5	LE : 12/10 Both: 14/10	LE : 6.6/10 Both: 9/10	100	###	Far: S	Right
(60)	RE : 12/10	RE : 6.6/10			Close: O	
S6	LE : 12/10 Both: 14/10	LE : 9/10 Both: 9/10	40	###	Far: X	Right
(58)	RE : 10/10	RE : 9/10			Close: X	
S7	LE : Both:	LE : Both:			Far:	Right
(59)	RE :	RE :			Close:	
S8	LE : 12/10 Both: 14/10	LE : 6.6/10 Both: 9/10	40	5	Far: X	Right
(56)	RE : 12/10	RE : 6.6/10			Close: X	
S9	LE : 12/10 Both: 12/10	LE : 6.6/10 Both: 9/10	60	4	Far: X	Right
(61)	RE : 10/10	RE : 9/10			Close: X	
S10	LE : 12/10 Both: 14/10	LE : 6.6/10 Both: 9/10	100	9	Far: X	Right
(62)	RE : 12/10	RE : 9/10			Close: S	
S11	LE : 9/10 Both: 10/10	LE : 6.6/10 Both: 6.6/10	**120**	9	Far: X	Right
(68)	RE : 8/10	RE : 6.6/10			Close: X	
S12	LE : 10/10 Both: 10/10	LE : 6.6/10 Both: 6.6/10	40	**13**	Far: X	Right
(63)	RE : 10/10	RE : 6.6/10			Close: O	
S13	LE : 10/10 Both: 12/10	LE : 6.6/10 Both: 6.6/10	40	**11**	Far: X	Right
(55)	RE : 9/10	RE : 9/10			Close: X	
S14	LE : 4/10 Both: 7/10	LE : **2.5/10** Both: 6.6/10	**140**	7	Far: X	Right
(62)	RE : 7/10	RE : 6.6/10			Close: X	

Normal values are <10cm for NPC and <100 (″) for stereoacuity. For two old subjects (S5, S6), we could not measure the NPC as they never reported double vision (represented by ###). Numbers in bold indicate beyond normal values.

Examination of the visual function was also done for all subjects, young (except for S8 and S11) or aged (except for S2 and S7). The purpose of this examination was to screen binocular visual function and vergence capabilities. We examined visual acuity at far (5 m) and at close distance (33 cm with Parinaud's reading test); binocular vision was evaluated using the Wirt stereoacuity test (or Titmus stereo test), based on polarized filters; the near point of convergence (NPC) and phoria was also measured. Absence of the balance problems was grossly evaluated with the Unterberger/Fukuda stepping test.

The dominant eye was evaluated by asking the subject to look through their hands a target at 5 m and then closing alternatively each eye to judge the eye for which the alignment was the best. As this test was made monocularly at far distance, we determined the dominant eye and not the prevalent eye that is identified binocularly at close distance e.g. inside the Panum's area (Heinrich et al., 2005). Only two of the young and three of the elderly subjects were left eye dominant; this number was insufficient for a comparison between left and right eye dominance. Consequently we excluded these subjects. Thus, posturography data come from 16 young (25.7 ± 2.7 years) and 14 old (61.2 ± 4.6 years) persons who were all right eye dominant.

2.2. Posturography

2.2.1. Platform characteristics

To measure the postural stability, we used a platform (principle of strain gauge) composed by two dynamometric clogs (Standards by Association Française de Posturologie; produced by *TechnoConcept*, Céreste, France). The excursions of the center of pressure (CoP) were measured during 51.2 s; the equipment contained an Analogical/Digital converter of 16 bits. The sampling frequency of the CoP was 40 Hz.

2.2.2. Visual target

A vertical screen was used to display a target along the vertical midline. The target was a letter "X" placed between two vertical segments. The angular size of the letter "X" was adjusted to subtend 1° for both viewing distances (200 and 40 cm). Each vertical line subtended 0.29° for both viewing distances.

2.2.3. Posturography testing conditions

Quiet stance posturography was done in a normally furnished experimental room with medium illumination. Subjects were placed on the platform and were asked to fixate the "X" target placed at the eye level. In different sessions, the vertical screen was placed at 40 and 200 cm from the subject. At 40 cm, the angle of vergence was 9° while at 200 cm it was 2°. For each distance, three conditions were run with fixation of the target under binocular, dominant or non-dominant eye viewing (DEV, NDEV, respectively). For the dominant and non-dominant eye viewing, a paper mask was placed in front of one eye; the mask was fixed around the subject's head by a rubber. The order of the distance was counterbalanced between subjects, and for each distance the order of the viewing conditions was also counterbalanced. During posturography, subjects wore their habitual spectacle correction and reported clear vision of the target for both distances. Among the elderly group, three wore their spectacle for near vision (S2, S4, and S13), one for the far vision (S6), and another subject did not need spectacles (S7); the remaining old subjects wore bifocal spectacles, thus correcting both far and near vision.

2.2.4. Postural parameters

We analysed the area of CoP, the standard deviations of antero-posterior (SDy) and of lateral body sways (SDx), and the variance of speed. Note that other relevant studies have examined the CoP (Isotalo et al., 2004) or the root-mean square of the CoP (Fox, 1990); the latter measure is similar but not identical to standard deviation we used here. Note that many recent studies use standard deviation of CoP (Gravelle et al., 2002; Hertel & Olmsted-Kramer, 2006). The area of CoP was calculated so that 90% of the instantaneous positions of the CoP were inside an ellipsoid (Gagey & Weber, 1999).

2.2.5. Statistical analysis

A mixed ANOVA design with two main factors, the distance (40 and 200 cm) and viewing condition according the ocular dominance (binocular, dominant or non-dominant eye viewing); and one inter-subject factor, the age of subjects (young and elderly). Post-hoc comparison was done by the Scheffé test; the effect of a factor is significant when the p-value was below from 0.05.

3. Results of the visual examination

The results are shown in Table 1 for the young and the old subjects. For young subjects, almost all values are in the normal range. They had perfect binocular vision and their ability to converge at near point (NPC) was normal i.e. under 10 cm (von Noorden, 1996a). In general, results from aged subjects show more remote point of proximal convergence which is normal, and for four of the subjects values of NPC are >10 cm. Stereoacuities were normal for the majority of the subjects; higher stereoacuity thresholds i.e. beyond 100″(von Noorden, 1996b) were observed for two from older subjects (S11 and S14). Such mild deviations from the adult normal threshold are expected for older subjects. Indeed, the visual acuity and the stereoacuity decrease with age (Ivers et al., 2000; Laitinen et al., 2005; Zaroff et al., 2003). Note that all aged subjects were able to converge the eyes appropriately without sensing double vision until 6–14 cm. Since our near posturography testing was done at 40 cm, all subjects were able to converge at this distance.

4. Postural measures

Results are shown in Table 2 which shows the group means and standard deviations for the three viewing conditions (binocular, DEV, and NDEV), for the two viewing distances (close and far), and for the two groups of subjects (young and aged). Next, we will present the results of ANOVA evaluating the effects of distance, viewing condition and age on each of the postural parameters.

4.1. Distance effect

There was a main effect of distance on most of the parameters tested, the area of CoP ($F_{(1,28)} = 10.2$, $p = .0034$), the antero-posterior body sway (or SDy, $F_{(1,28)} = 15.7$, $p = .00046$) and the variance of speed ($F_{(1,28)} = 4.86$, $p = .036$); all these parameters were significantly smaller at near distance.

4.2. Effect of viewing condition

The viewing condition had no main effect either on the area of CoP or on the SDx, but it had an effect on SDy ($F_{(2,56)} = 4.79$, $p = .011$). Antero-posterior instability was greater when viewing with the NDEV than when viewing with both eyes ($p = .032$) or with the DEV ($p = .029$). There was no significant difference between the latter two conditions (both eyes viewing, dominant eye).

Table 2
Means and standard deviations of area of CoP, standard deviation of lateral, of antero-posterior body sway, and of variance of speed for each viewing condition and for each distance for young and old subjects

Parameters	Distance					
	40 cm			200 cm		
	Viewing condition			Viewing condition		
	Binocular viewing	Right eye dominant	Left eye non-dominant	Binocular viewing	Right eye dominant	Left eye non-dominant
Surface of CoP (mm^2)						
Young	107 ± 98	127 ± 84	133 ± 92	179 ± 116	133 ± 109	170 ± 110
Elderly	111 ± 99	133 ± 110	129 ± 102	178 ± 164	156 ± 146	139 ± 114
Standard deviation of lateral sway (mm)						
Young	2.1 ± 1.2	2.4 ± 1.1	2.1 ± 0.9	3.0 ± 1.7	2.3 ± 1.4	2.4 ± 0.9
Elderly	2.2 ± 1.2	2.4 ± 1.4	2.1 ± 0.8	2.3 ± 0.9	2.3 ± 1.4	2.1 ± 1.2
Standard deviation of antero-posterior sway (mm)						
Young	3.5 ± 1.4	3.9 ± 1.3	4.5 ± 2.0	4.7 ± 1.5	4.5 ± 2.0	5.4 ± 2.3
Elderly	3.5 ± 1.3	4.0 ± 1.6	4.7 ± 2.6	5.1 ± 2.7	4.3 ± 1.7	4.5 ± 1.8
Variance of speed (mm^2/s^2)						
Young	24.9 ± 13.0	28.9 ± 17.6	34.0 ± 36.6	27.3 ± 15.8	27.4 ± 16.6	33.3 ± 20.7
Elderly	32.7 ± 22.0	36.1 ± 25.1	38.5 ± 28.2	45.3 ± 33.9	49.0 ± 41.0	46.5 ± 34.2

4.3. Interaction between distance and age

Age had no effect on the area of CoP or on the SDx and the SDy. There was no main effect either on the variance of speed. However, there was a significant interaction between age and distance on variance of speed ($F_{(1,28)} = 4.69$, $p = .039$): the speed variance was higher for old subjects at the distance of 200 cm in comparison with young ($p = .00058$, see Fig. 1).

4.4. Interaction between distance and viewing condition

Interaction between the distance and the viewing condition was significant for the area of CoP ($F_{(2,56)} = 3.73$, $p = .030$), but did not reach the significance for the SDx ($F_{(2,56)} = 2.55$, $p = .087$) and for the SDy ($F_{(2,56)} = 2.64$, $p = .080$).

The area of CoP under the binocular viewing condition was significantly higher at far distance than under the binocular viewing at near ($p = .0028$, Fig. 2). In contrast, the monocular viewing produced similar results at both distances.

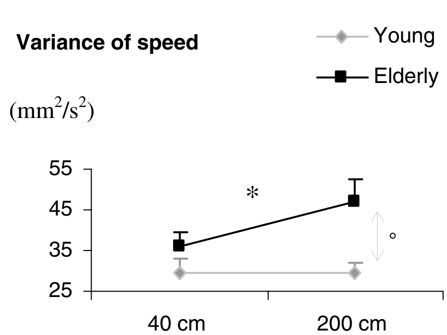

Fig. 1. At the distance of 200 cm, elderly subjects presented more variance of speed than younger one ($p < .05$, represented by a circle). The distance effect was significant only in elderly group ($p < .05$, represented by an asterisk).

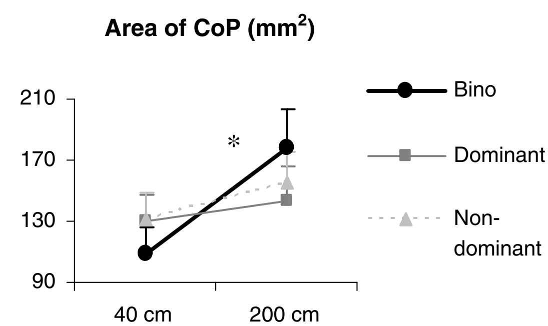

Fig. 2. The effect of distance was significant only under binocular viewing ($p < .05$, represented by an asterisk) in comparison with dominant and non-dominant eye viewing.

5. Discussion

This study revealed four results: (i) a robust effect of distance on several parameters; (ii) an effect of viewing condition only on antero-posterior sway; (iii) an effect of age only on the speed variance, (iv) an interaction between distance and viewing condition.

5.1. Distance effect

Proximity decreased the area of CoP, the standard deviation of antero-posterior sway (SDy) and the variance of speed. These results confirm our previous reports (Kapoula & Le, 2006), and are consistent with other studies (Bles et al., 1980; Brandt et al., 1986; Paulus et al., 1989, 1984) who also reported a decrease of body sway at near distance.

5.2. Viewing condition

There was a main effect of viewing condition only on standard deviation of antero-posterior body sway (SDy). Under binocular or under dominant eye viewing, the SDy was significantly smaller than under non-dominant eye viewing. These results are consistent with Isotalo et al. (2004) who found no effect of ocular dominance on the area of CoP. The effect observed here on SDy indicates that viewing condition influences postural control in a finer way. The antero-posterior sway can cause substantial variation of the angular size of the retinal image, particularly when fixating a near target; i.e. a few centimetres of body displacement in depth could correspond to large change of the vergence angle. In contrast, the medio-lateral body sway displaces the image only laterally. A possible interpretation is that the dominant eye could be more efficient to detect changes of angular size of retinal slip resulting from antero-posterior body sway. Fu and Boothe (2001) showed that monkeys presented threshold asymmetry between the two eyes but only for lateral motion detection: they called the "best" eye the eye showing the lower threshold (irrespectively from eye dominance). To our knowledge studies that evaluated the thresholds of motion detection in humans almost always compare binocular versus monocular viewing, regardless of the ocular dominance. Thus, the threshold of motion detection was found to be higher under monocular than under binocular viewing (Rose, 1978, 1980). Similar studies on motion perception in depth are missing.

5.3. Age

The group of elderly presented increased variance of speed at far distance in comparison with young subjects. As we mentioned above, the variance of speed is related to the energy released by the leg muscle activity in order to stabilize posture and is consistent with studies from Amiridis et al. (2003) and Jonsson et al. (2005) who reported increased muscle activity in aged subjects. The increment of variance of speed seems to be the first sign of senescence in postural control.

The absence of interaction between age and viewing condition indicates that posture in elderly was not affected by monocular viewing, contrary to what we expected (see Section 1).

5.4. Interaction between distance and viewing condition

The most important finding is that binocular viewing provides very different results for the two viewing distances while monocular viewing (with either eye) changes little with distance. As shown in Fig. 2, at near distance binocular viewing provides the smallest area of CoP while at far distance it yields the largest area. As visual cues are richer and visual performances are better in general under binocular viewing, our results are rather surprising since McKnight, Shinar, and Hilburn (1991) found that the visual acuity is better under binocular vision than under monocular vision. Our results of visual acuity measured at far (Table 1) presented a similar tendency in most of subjects. Yet, postural stability is the worst under binocular viewing.

McKnight et al. (1991) also showed that perception of distance in depth was better under binocular vision than under monocular vision. However, studies from Magne and Coello (2002), Servos (2000), Servos and Goodale (1994), Servos, Goodale, and Jakobson (1992) indicate that the superiority of binocular viewing for distance evaluation is observed only in active tasks (e.g. reaching a target) and not under static conditions. As perceptual judgement of depth seems equal between binocular and monocular viewing in static condition, distance evaluation cannot be the cause of decreased posture stability under binocular viewing.

The retinal slip yielded by body sway decreases with increase of distance for geometric reasons and may become harder to detect (Bles et al., 1980; Brandt et al., 1986; Paulus et al., 1989, 1984). Such decrement, however, should be similar under binocular viewing and under monocular viewing. Thus, differences in retinal slip under binocular and monocular viewing at far cannot explain our results either. Similarly, Guerraz et al. (2000) showed that the influence of motion parallax (relative motion between objects) on postural stability was the same for binocular and monocular viewing.

The increase of postural instability with both eyes viewing at far is reminiscent of the behaviour of hunter and archer during the aiming phase. It is common experience that hunter and archer spontaneously close one eye to aim more accurately their target. Coull, Weir, Tremblay, Weeks, and Elliott (2000) found that monocular vision is sufficient for precise control of limb movement during both grasping and aiming tasks. This behaviour could help to eliminate any confusing or inconvenient information from the other eye.

In a previous study (Kapoula & Le, 2006), we suggested that the contraction of medial rectus extra-ocular muscles caused by the sustained convergence of the eyes at near was responsible for better postural stability. Indirect evidence about the link between extra-ocular muscle activity and posture comes from the study of Roll and Roll (1987) who showed that vibrations on the superior recti shifted the mean position of the body forward while vibration of the inferior recti shifted this position backward. In contrast to convergence, divergence of the eyes needed to fixate at far distance is considered to involve relaxation of the medial recti. Relaxation of extra-ocular muscles would decrease the tone of the posture. Could relaxation and divergence of the eyes be more pronounced under both eyes viewing? The phoria tests show that the majority of our subjects of either group presented exophoria i.e. outward deviation of the briefly covered eye (see Table 1). Consequently the posture should be less stable when viewing monocularly at far than when viewing binocularly and that is not what we observed. It is not known, however, whether occlusion of one eye for 51.2 s (as was the case during the posturography test) creates sustained outward deviation of the covered eye. Further studies recording eye movements could be useful to elucidate this point.

When both eyes are viewing, binocular cues such as binocular disparity are also used. Visual stabilization of body sway involves both sensitivity to movement in depth and sensitivity to lateral visual motion. It is possible that the sensitivity of postural control to changes of binocular disparity and to visual motion in depth resulting from fore-aft body sway decreases strongly at far distance. Indeed, for geometric reasons, sensitivity of disparity resulting from fore-aft visual sway decreases more with viewing distance than sensitivity to retinal position resulting from lateral body motion. Low sensitivity of visual motion in depth should induce high SDy values; yet our results show significant effect of distance on the area of the CoP but not on the SDy. Even though, SDy and SDx are believed to be controlled by distinct mechanisms, some interaction exists (Winter et al., 1996, 2003). Thus, the interaction effect of distance and viewing condition on CoP could be related to a strong decrease of visual motion sensitivity in depth based on binocular disparity cues at far distance. Again, further studies with eye movement recordings could be useful to elucidate this point.

Finally, cognitive function and emotional context can be also involved in our results. It is known that such factors influence the posture. Several studies use an additional cognitive task during posturography, such as visuo-spatial discrimination, word categorization, or generation of random number (Dault, Frank, & Allard, 2001), aloud repetition of letters with or without memorization of words formed by these letters (Dault et al., 2001; Dault, Yardley, & Frank, 2003). Such tasks have been found to reduce CoP excursions via the attention and the working memory mechanisms. Emotional context can be modulated, for example, by placing subjects on an unpredictable moving platform or at the edge of a high height surface. This provokes anxiety and fear of falling (Adkin, Frank, Carpenter, & Peysar, 2002; Carpenter, Frank, Adkin, Paton, & Allum, 2004). In such situations, the central nervous system adopts a cautious strategy and the subject controls their posture tighter which is manifested by reduced postural sway and increased frequency sway. At far distance, postural stability should be always decreased, because sensitivity to visual signals becomes weaker (retinal slip, motion lateral or in depth). On the other hand, when visual inputs are disrupted e.g. by covering one eye (monocular viewing), our subjects could increase their attention in order to correctly maintain the postural stability. Additional attention could help them to control tighter their posture regardless of the distance. Under binocular viewing, subjects may feel more comfortable, the attention factor intervenes less and thus, the distance effect becomes more visible.

In conclusion, this study shows that postural stability decreases under binocular viewing as distance increases while under monocular viewing the stability is the same regardless the distance. Increased sway at far with both eyes viewing is attributed to reduced sensitivity to visual motion in depth based on binocular disparity cues. For monocular viewing, we argue that covering one eye increases attention that allows tighter posture control regardless of the distance.

Acknowledgments

Authors thank subjects and F. Jurion for visual examination help. Special thanks to two anonymous referees and to Dr. T. Eggert for their insightful comments. T.T. Lê was support by European Union (QLK6-CT-2002-00151: EUROKINESIS) and CNRS/CTI, Handicap contract.

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